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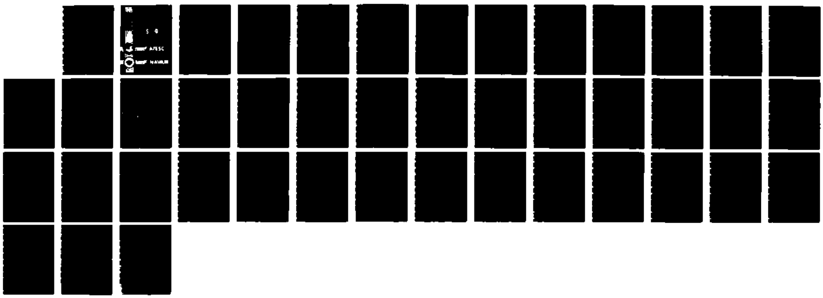

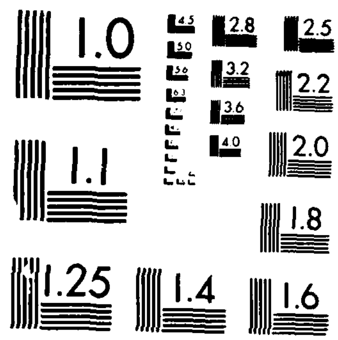

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Fire Performance Evaluation of Solid Aqueous Film–Forming Foam (AFFF)

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The fire performance of solid AFFF firefighting foam purchased from the 3M Company was determined and compared against the performance of liquid 3 percent concentrate which is on the Navy Qualified Products List (QPL). Twenty-eight and 50-square-foot fire tests specified in MIL-F-24385C were used to measure fire performance. A limited number of large-scale (1000-square-foot) fire tests were also conducted. Several mixing techniques were used to prepare solution samples at agent-to-water ratios of 6 grams per liter and 8 grams per liter. A total of 47 fire tests were conducted.

In all tests, the fire was extinguished using solutions prepared with solid AFFF. These solutions averaged longer times to control and extinguish hydrocarbon fuel fires when compared to solutions prepared with 3 percent liquid AFFF concentrate. Less than desirable burnback and mixing characteristics were also identified. Because there is potential to achieve significant agent space and weight reductions by using (continued)

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19. ABSTRACT (continued)

a solid AFFF, additional testing and evaluation is recommended. Specific recommendations include evaluation of solutions prepared by increasing the solid agent-to-water ratio, or reformulation of the solid agent to improve performance. Super-concentrated AFFF (proportioned at 1 percent or less) and concentrates prepared by reconstituting a base AFFF formulation also have potential to reduce space and weight requirements compared to existing 3 and 6 percent AFFF concentrates.

SUMMARY

The fire performance of solid AFFF firefighting agent provided by the 3M Company was determined and compared against the performance of liquid 3 percent AFFF concentrate which is on the Navy Qualified Products List (QPL) and which meets the requirements of the AFFF specification (MIL-F-24385C). A total of 47 fire tests were conducted, and data from previous specification tests are included for comparison. Foam solutions were prepared with solid agent at agent/water ratios of 6 grams per liter and 8 grams per liter, as recommended by the manufacturer. In all tests, the fire was extinguished, using solutions prepared with solid AFFF. These solutions averaged longer times to control and extinguish 28-square-foot, 50-square-foot and 1,000-square-foot hydrocarbon pool fires when compared to solutions prepared with 3 percent liquid concentrate. The AFFF prepared with the solid agent did not consistently meet the fire extinguishing and burnback requirements of the MIL SPEC. For example, only three of the eighteen 28-square-foot fire tests conducted using 8 g/L solid agent-to-water ratio met MIL SPEC extinguishment criteria, and only two of these tests met burnback criteria. Foam produced from the solid agent generally had poor sealing capability and reflash was frequently observed after 90-percent control.

Several mixing techniques were used; a propeller mixer, a mixing chamber apparatus and a pipe chamber apparatus. The propeller mixer circulated water and solid agent to produce a concentrate or foam solution, depending on the water/agent ratio used. The mixing chamber and pipe chamber methods used 1 1/2-inch hose and pumps to dissolve the solid agent by recirculating water through the solid material. It is feasible to dissolve the solid agent into a concentrate within 3 minutes or less, given a sufficient flow velocity in the mixing water stream. Storage time of a solution or concentrate prepared with solid agent may affect extinguishment performance, but additional testing is required to quantify the degree of the problem.

Additional fire tests should be performed with an increased solid/water ratio, to determine if increasing the solid agent concentration will improve performance. Otherwise, the solid pellets would have to be reformulated to meet the criteria of the MIL SPEC AFFFs now in use.

Alternatives to the solid agent may be a superconcentrated AFFF, proportioned at 1 percent or less or reconstituting an AFFF concentrate by adding water to a liquid or a solid agent to create a 3 percent or 6 percent concentrate. A preliminary fire performance and hardware analysis must be performed to determine the feasibility of these concepts.

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PREFACE

This report was prepared by Hughes Associates, Inc., 2730 University Blvd. West, Wheaton, Maryland 20902, under Contract Number N0014-84-C-2200, for the Naval Research Laboratory. This work was sponsored by the U.S. Air Force Engineering and Services Center (AFESC), HQ AFESC/RD, Tyndall Air Force Base, Florida 32493, and the Naval Air Systems Command, HQ NAVAIR, Washington, DC 20361, through an agreement with the Naval Research Laboratory, Washington, DC 20375. Mr Joseph L. Walker was the HQ AFESC technical program manager. Mr James Calfee and Ms Phyllis Campbell provided technical program management for NAVAIR. This report summarizes work done between 23 April 1984 and 14 September 1985.

The assistance of Dr Homer W. Carhart and Dr Joseph T. Leonard of the Naval Research Laboratory, Chemistry Division is appreciated. Thanks are also extended to the firefighting team at the Chesapeake Beach Detachment of NRL, particularly Mr Ralph Ouellette, for their assistance in performing the fire tests.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

A. BACKGROUND

The United States DOD components must provide fire protection for their worldwide bases/ships. An integral part of the protection is the deployment of crash rescue firefighting units, such as the P-4/P-19 multipurpose firefighting vehicles, equipped with AFFF concentrate storage tanks and proportioning systems for large-volume foam application. The firefighting vehicles are air-transportable, and space and weight considerations of the vehicle and associated agents and hardware are logistically important.

The 3M Company of St. Paul, Minnesota has developed a solid AFFF pellet material which, when dissolved with water, can be used as a firefighting agent on Class B hydrocarbon fires. Depending on the ratio of solid agent to water, the solid AFFF can provide potential weight and space savings of up to 75 percent in the transportation mode compared to MIL SPEC 3 percent AFFF currently on the Qualified Products List (QPL). On this basis, the solid agent appears to be an attractive alternative to 3 percent (or 6 percent) AFFF concentrate.

Integration of the solid agent could be accomplished in a number of ways. For purposes of preliminary fire test analysis of the agent, it was anticipated that solid AFFF could be phased-in in the following manner:

1. <u>No hardware improvements to the P-4/P-19 crash rescue vehicles</u> - bulk-ship the solid agent to the site, mix as a concentrate and store as a concentrate in the vehicle concentrate storage tank.

2. <u>Interim hardware improvements to the P-4/P-19</u> - retrofit a mixing chamber onto the vehicle with solid agent stored in the mixing chamber and dissolve into a concentrate while the vehicle is en route to a crash scene (hence, the requirement for quick dissolving time). The concentrate then would be proportioned as needed, using the existing proportioning systems.

3. <u>Hardware modifications to newly designed vehicles</u> - in the form of an integrated mixing chamber or, possibly, a cartridge of solid agent with water inlet and approximately 3 percent firefighting agent discharge. Immediate mixing and use has been accomplished for portable extinguishers, but not for high-volume flow rates.

Preliminary discussion between the USAF/Navy and the manufacturer* resulted in the establishment of the following goals for solid AFFF compared to AFFF concentrate currently approved for military use:

1. A weight reduction of 75 percent

2. A volume reduction of 70 percent

3. Maximum dissolving time of 3 minutes

Because of their involvement with the development of AFFF, the Naval Research Laboratory was tasked by HQ AFESC/HQ NAVAIR to evaluate the solid AFFF material. A two-phase program was anticipated. The objective of the first phase was to determine if the solid AFFF, when dissolved in fresh water, exhibits fire-extinguishing characteristics equivalent to liquid 3 percent AFFF concentrate proportioned with fresh water when tested on a small and large scale. If this work proves successful, hardware and related specification requirements would be addressed in a future phase. This report describes the initial fire performance testing phase of the solid AFFF material.

B. OBJECTIVES

The primary objective of this analysis was to determine if an acceptable AFFF foam concentrate could be prepared from the currently available formulation of solid AFFF. This was to be done by comparing fire extinguishing and burnback characteristics of solid AFFF against the 3 percent AFFF performance criteria in MIL-F-24385C. Another objective was to investigate mixing characteristics while evaluating fire performance.

---

* J.A. Pignato, 3M Company, St. Paul, MN, private communication, minutes of meeting with USAF HQ AFESC/RD, October, 1981.

SECTION II

EXPERIMENTAL PROCEDURE

A. PROCEDURE

Initial efforts in the evaluation focused on preparing a "concentrate" from the solid AFFF using 1.67 pounds of agent per gallon of water (200 g/L). This equates to a ratio of 6 g/L of solid material in water when the concentrate is proportioned at 3 percent to produce firefighting foam. Later in the investigation, the solid agent-to-water ratio was increased to 2.22 pounds of agent per gallon of water (267 g/L). This equals 8 g/L when proportioned at 3 percent. For the remainder of the report, the designation 6 g/L and 8 g/L will be used to designate the final solid-to-water ratio of the firefighting foam, independent of the method in which the agent was initially prepared (either as a concentrate or a firefighting foam solution). No efforts were made to create a foam solution directly from a "charge" of solid agent without recirculating the water to fully dissolve the solid material. The manufacturer currently uses the "solid-charge" technique in a commercially available hand-held portable fire extinguisher.

The solid agent was procured from the 3M Gorecki Facility, Lot 33, Code SC 786. The average pellet size is 3/16 inch by 3/16 inch. The bulk (dry-packing) density is 0.7 g/L. The full density (completely packed without any air space) is 1.4 g/L. After initial tests, another lot was sent by 3M for testing. Lot 60103-28, received on July 27, 1984, had a somewhat different appearance and characteristic size. It did not have the sticky feeling of the other agent, but was dry to the touch. Two fire tests were performed, using the new lot.

B. MIXING PROCEDURE

Initial bench-scale tests were performed to determine the refractive index of the solid AFFF when dissolved into a concentrate. An American Optical Corporation Refractometer, Model 10450, with integral water bath connections, was used to determine the refractive index. Bench-scale samples of concentrate were prepared, using 50 milliliters of water and 10 grams of solid agent. The solid agent was dropped into a beaker and stirred vigorously until completely dissolved, as visually determined. Refractive indices were recorded at a constant temperature of 25°C, ± 2°C.

Solid agent AFFF was prepared for experimental fires, using the stirrer and two different large-scale mixing apparatuses. Initially, concentrates were prepared using a laboratory propeller stirrer with a 2 1/2-inch diameter paddle at the end of

the shaft, which rotated at 1,550 rpm. Typically, 5-gallon concentrate samples were prepared by adding solid agent over a 15-minute timespan so that the solid pellets would be circulated and not sink to the bottom of the mixing container. During the initial dumping of solid agent, the shaft and paddle of the stirrer were centered in the container, with the paddle approximately 2 inches above the bottom of the mixing container. After all of the solid agent had been dumped into the mixing container, the concentrate was allowed to mix for at least an additional hour. During this time, the height of the paddle above the bottom of the container was intermittently changed to improve mixing. This technique (small-scale stirrer to create a concentrate) was investigated in the anticipation that, prior to deployment and retrofitting of larger-scale mixing chambers on crash rescue vehicles, the solid agent could be deployed in the field, mixed by some easy means, and stored in the concentrate tank on board the crash rescue vehicle.

Two large-scale batch mixing methods were used in the investigation. The first, designated as the "mixing chamber," is based on a concept developed in early discussions with 3M and the AFESC/NAVAIR. Figure 1 shows the container, which measures 52 inches long by 36 inches wide by 6 inches deep. The chamber is partitioned to create six 52-inch by 6-inch chambers in which solid agent can be loaded. This creates a path by which water can circulate through the agent. There is a 1 1/2-inch diameter inlet and outlet at the upstream and downstream ends of the chamber, respectively. The total capacity of the chamber when all six sections are loaded is 282 pounds of solid agent. For the purposes of these tests, a steel sieve is installed at the end of the second chamber area so that only two sections are used. A commercially available nylon scrubbing pad is used as a filter at the upstream side of the sieve to prevent solid agent from discharging into the remixing tank. Ninety-four pounds of agent were used in the test, along with 56.5 gallons of water. A 25 gpm pump recirculated the water at 15 psi to dissolve the pellets into a 6 g/L concentrate. The 25 gpm pump is used to create a water velocity in the chamber similar to the velocity of 18 feet per minute described by the manufacturer as the velocity required to dissolve the pellets in 3 minutes at 25°C. At flow rates greater than 25 gpm, the pump tended to draw a suction in the soft-sleeve hose used in the experiment. During the course of the mixing, power was lost to the pump several times because of a breaker outage. The concentrate was recirculated for 10 minutes. The refractive index of the solution was taken at increasing time intervals to determine the degree of dilution.

A second water stream dissolving method, designated as the "pipe chamber" method, was used to dissolve pellets on a large scale. This method involves the use of an 8 foot long section of 4-inch diameter steel pipe. A 1 1/2-inch diameter fire hose is attached to a 4-inch by 1 1/2-inch reducer coupled at the

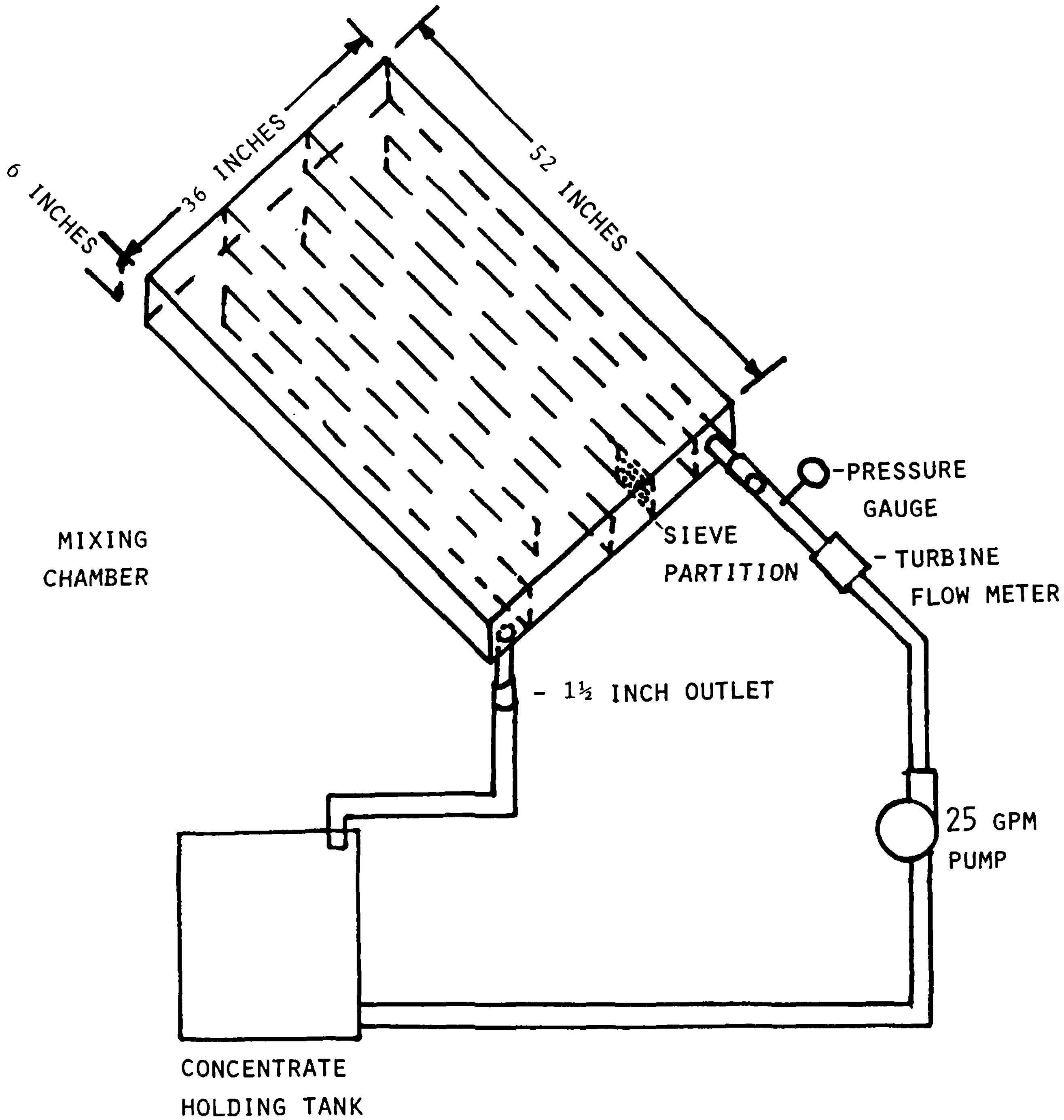

Figure 1. Mixing Chamber Apparatus

upstream end of the pipe. The discharge has a cap with holes drilled in the end to permit flow of mixed agent concentrate through the cap. Just upstream of the cap, a nylon filter is installed to prevent passage of solid agent into the recirculation tank. Water is recirculated using a 500 gpm fire department pumper. Inlet pressure to the pipe chamber is set at 100 psi, which creates an average flow through the pipe of 150 gpm. Estimated velocity in the pipe without a solid charge is greater than 200 feet per minute. Typically, a 16.65 pound charge was used to create a 3 percent foam solution with 250 gallons of water (8 g/L). A schematic diagram of the mixing arrangement is shown in Figure 2.

C. SMALL-SCALE FIRE TESTS

The method used for preliminary fire performance evaluation of the solid agent is the 28-square-foot fire test described in MIL F-24385C, Military Specification for Aqueous Film-Forming Foam Liquid Concentrate (Reference 1). Fresh water was used in all tests. The test uses a 6-foot diameter steel pan in which 10 gallons of leaded motor gasoline is floated on top of a water substrate. After a 10-second preburn, the fire is vigorously attacked by a trained operator applying premixed foam solution at a rate of 2 gpm. Nozzle pressure is fixed at 100 psi. The percentage of fire extinguished at increasing time intervals is recorded, along with extinguishing time. Agent is continuously applied after extinguishment for a total of 90 seconds. Within 60 seconds after the completion of foam application, a burning pan (1 foot in diameter with 2 inches at the high side) is placed in the center of the 28-square-foot pan and a timer started. When it appears that the fire has spread outside the pan so that burning will continue after pan removal, the pan is removed. The burnback time is that time at which it is estimated that 7 square feet (25 percent) of the total area is involved in flames.

The fire performance of solid agent was compared to results of tests using 3M FC 203CE 3 percent foam concentrate (Lot 501) which is approved for service use. MIL F-24385C requires fire extinguishment in 30 seconds and a minimum time of 360 seconds (6 minutes) before 25 percent of the area has "burned back."

Several tests were conducted using the 50-square-foot fire test described in the MIL SPEC. The same test scenario as the 28-square-foot test was used, except that an 8-foot diameter circular area on the ground is used as a test bed. Agent application and burnback procedures are the same. Estimates of the percentage of fire extinguished at 10, 20, 30, and 40 seconds after foam application is begun are recorded and totaled to give the "40-second summation" value. The requirement for the 40-second summation is a minimum of 320 percent. Maximum extinguishment time permitted is 50 seconds, and a minimum

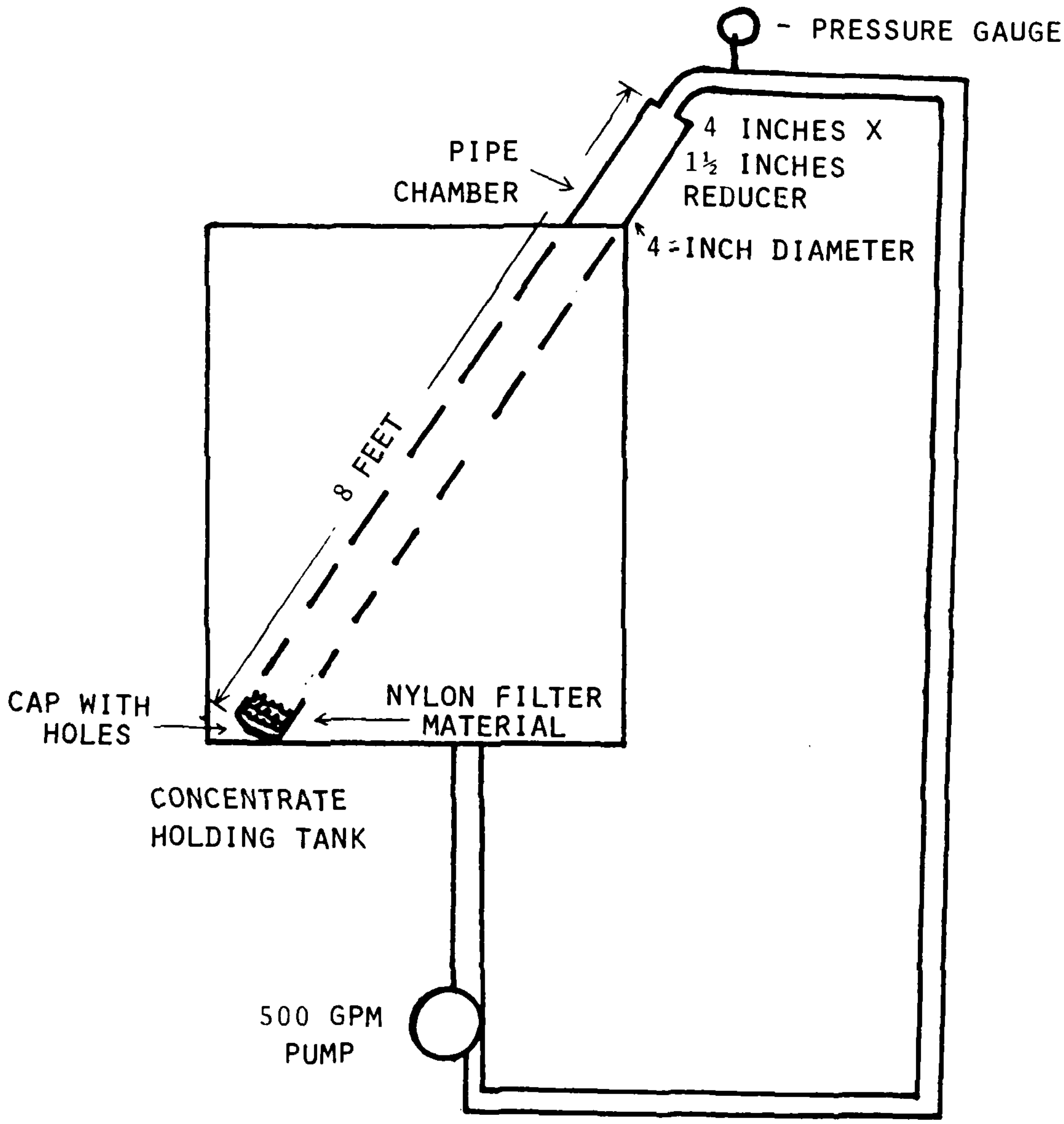

Figure 2. Pipe Chamber Mixing Apparatus

burnback time of 360 seconds is required. AV GAS is the fuel used in the 50-square-foot fire tests. Fresh water was used to prepare the foam solution.

D. LARGE-SCALE FIRE TESTS

Larger fire tests were performed to compare the solid agent to 3 percent AFFF which is on the QPL. The test fire is a 1,000-square-foot (31.6-foot by 31.6-foot) fire area with 200 gallons of AV GAS floated on a water substrate. After a preburn of 15 seconds, AFFF is applied to the fire at a rate of 60 gpm by a trained firefighter, using a 1 1/2-inch hand line. An Elkhart variable flow (60 - 95 -125 gpm), variable stream nozzle set in the straight stream pattern is used at 100 psi. In conditions involving an ambient wind, the agent is applied from the upwind side of the fire. Ninety percent control time and extinguishment time are recorded. Ninety percent control is the time at which 900 square feet of the fire area is extinguished as determined by observation.

SECTION III

TEST RESULTS

A total of 47 fire tests were conducted. All fire test results are tabulated in Appendix A. Averages of selected fire test results have been summarized in Tables 1, 2, and 3. Table 1 is a comparison of the fire performance of solid AFFF diluted at a rate of 8 g/L using the pipe chamber mixing method and 3 percent AFFF concentrate. Table 2 is the average result of 6 g/L and 8 g/L solutions based on method of mixing, method of sample preparation (concentrate or firefighting agent solution), and storage time (time between dissolving and use) of the prepared sample.

A. BENCH-SCALE TESTS

1. Refractive Index

Table A-1 reports data from bench scale samples of 3 percent and solid AFFF. The table shows the refractive indices of full strength concentrate (3 percent concentrate) and varying solutions prepared by adding water to the concentrate. These data could be used to evaluate the mixing of solid AFFF concentrate or solution samples prepared with the propeller stirrer, mixing chamber, or pipe chamber. Table A-1 indicates that a full-strength concentrate has a refractive index of at least 1.3529. For 6 g/L solutions, the refractive index ranged from 1.3331 to 1.3332. For an 8 g/L solution, the refractive index ranged from 1.3333 to 1.3335. The manufacturer suggested that the refractive index of an 8 g/L solution should be approximately 1.3338. Later tests revealed that these refractive indices were slightly less than those recorded with large-scale mixing techniques.

2. Fluorine Content

Fluorine content of various samples of QPL 3 percent AFFF and solid AFFF were determined by an independent testing laboratory. Table A-2 shows that the 6 g/L solid agent samples have approximately one-half the fluorine content by weight of QPL 3 percent AFFF. The table also shows that propeller mixing of the solid agent yields a higher fluorine content than the bench-scale mixing method for the same ratio of solid to water. This indicates that larger scale mixing methods may dissolve the agent better than the bench-scale methods.

TABLE 1. FIRE PERFORMANCE COMPARISON OF SOLID AFFF AND 3 PERCENT CONCENTRATE

	Time To 90 Percent Control (SEC.)	Time To Exting. (SEC.)	40 Sec. Sum. PERCENT	Time To 25 Percent Burn Back (SEC.)
28-Square-Foot				
8 g/L Solid, Pipe Chamber Mix	23	33	--	331
QPL 3M 203 (3 Percent) Concentrate	17	26	--	464
Mil Spec Criteria	N/A	30	N/A	360
50-Square-Foot				
8 g/L Solid, Pipe Chamber Mix	32	60	266	--
QPL 3M 203 (3 Percent) Concentrate	26	40	345	509
Mil Spec Criteria	N/A	50	320	360
1,000-SQUARE-FOOT				
8 g/L Solid, Pipe Chamber Mix (One Test)	16	44	--	--
QPL 3M 203 (3 Percent) Cconcentrate	18	31	--	--

TABLE 2. DISSOLVING AND STORAGE VS. 28-SQUARE-FOOT FIRE PERFORMANCE, 8 g/L PROPELLOR AND PIPE CHAMBER MIXING

	Tests	Initial Preparation	Storage Time[1]	Time to 90 Percent Control (sec.)	Time to Exting. (sec.)	Time to 25 Percent Burnback (sec.)
Propeller Mixing	11,25	Concentrate	Less than 5 min.	27	34	315
	12,17,18,26	Concentrate	Greater than 5 min.	27	34	305
		Average, Propeller Concentrate		27	34	309
	13,27	Solution	Less than 5 min.	22	33	321
	14,28	Solution	Greater than 5 min.	24	38	310
		Average, Propeller Solution		23	35	315
		Total Average of Propeller Mixing		25	34	311
Pipe Chamber Mixing	19,23	Solution	Less than 5 min.	24	31	349
	15,16,20,21 22,24	Solution	Greater than 5 min.	23	34	324
		Total Average of Pipe Chamber Mixing		23	33	331

[1]Time between dissolving and use.

TABLE 3. DISSOLVING AND STORAGE TIME VS. FIRE PERFORMANCE, PIPE CHAMBER MIXING

A. 28 SQUARE-FOOT TESTS, 8 GAL SOLID AGENT, PIPE CHAMBER MIXING METHOD

Test No.	Recirculation Time (Min.)	Time From Mix To Use	Refractive Index (Top of Tank)	90 Percent Control Time (Sec.)	Exting. Time (Sec.)	Time To 25 Percent Burnback Back (Sec.)
15	3	45 min.	--	26	32	309
16 (same sample as Test 15)	3	60 min.	--	26	39	297
19	5 1/2	5 min.	1.3339	20	25	378
20 (same sample as Test 19)	5 1/2	20 min.	--	27	34	317
21 (same mix as Tests 19 and 20)	Originally 5 1/2 min.	17 days	1.3341	18	30	376
22 (same sample as Test 21)	Originally 5 1/2 min.	17 days	--	20	36	--
23	10	5 min.	1.3341	28	37	320
24	10	20 min.	--	22	32	323

B. TEST 21 & 22 SAMPLE REFRACTIVE INDEX PROFILE

	Sample 1	Sample 2
Top of Tank	1.3341	1.3341
Middle of Tank	1.3335	1.3341
Bottom of Tank	1.3341	1.3341
Discharge outlet (bottom)	1.3341-42	1.3341-42

C. MIXING OF SOLID AGENT IN TESTS 23 & 24

	Refractive Index
Water prior to recirculation	1.3331
1 min. after start of recirculation	1.3340
2 min. after start of recirculation	1.3341
3 min. after start of recirculation	1.3341
4 min. after start of recirculation	1.3341

B. FIRE TESTS

All fire test results, including comparative data from QPL tests, are detailed in Tables A-3 through A-6. During fire testing, it became obvious that the recommended 6 g/L solid-to-water ratio solution was not performing as well as solution made from QPL 3 percent concentrate, and that, with one exception, 6 g/L could not meet the MIL SPEC requirements for extinguishment and burnback. Based on these data and recommendations from the manufacturer, the ratio of solid to water was increased to 8 g/L in firefighting solution.

A total of thirty-three 28-square-foot tests, four 50-square-foot tests, and ten 1000-square-foot tests were conducted. In addition, data from 9 QPL tests are included in the fire performance comparison.

Table 1 indicates average extinguishment and burnback characteristics of 3 percent foam for 28-square-foot, 50-square-foot and 1,000-square-foot fires, as well as extinguishment and burnback requirements of the MIL SPEC. These data are used in the following sections to compare the results of the solid AFFF with 3 percent concentrate and MIL SPEC requirements. The data on 3 percent liquid concentrate include tests conducted for this evaluation and for qualification tests previously conducted at NRL (including tests for PKP compatibility and tests with saltwater). All 3 percent liquid concentrate tests meet MIL SPEC requirements, except Test 4 (Table A-4) where extinguishing time is 31 seconds instead of 30 seconds.

1. 6 g/L - Propeller Mixing

Solid AFFF concentrate samples were prepared using the propeller mixer with an agent-to-water ratio of 200 g/L. The premix solution then contains 6 g/L solids. The overall average values for 90 percent control time, extinguishment time and 25 percent burnback time for the 6 g/L, 28-square-foot fire tests are 26 seconds, 38 seconds and 313 seconds, respectively, for four tests (Table A-3, Tests 1, 2, 9, and 10). None of the tests meet the requirements of the MIL SPEC and the results are less satisfactory than the QPL 3 percent results.

In Tests 9 and 10, the concentrate was prepared 6 days before the test, and then remixed for 30 minutes before testing.

Ninety percent control time and extinguishment time for two 1,000-square-foot fire tests conducted with 6 g/L samples are 22 seconds and 59 seconds, respectively, compared to average results for QPL 3 percent concentrate of 18 and 21 seconds, respectively (See Table A-6, Tests 1, 2, 5, 8, and 9). The 6 g/L solution

used in the 1,000-square-foot tests had been prepared at least 40 days before testing.

2. 6 g/L - Mixing Chamber

The 52-inch by 36-inch mixing chamber was used to prepare a 200 g/L concentrate. Average refractive indexes of samples taken during the recirculation period and after dissolving are shown in Table A-7. The data, particularly the end concentrate data, show a wide variation. In one case, the reading during dissolving (plus 3 minutes into the recirculation time) was higher than the end results. At the end of the 10-minute recirculation period, the mixing chamber was opened and it was observed that 10-20 percent of the solid agent had not been dissolved. Apparently, the water stream created by the 25 gpm pump was sufficient to dilute the solid pellet down to a certain level, after which the water just flowed on top of the solid agent bed. The data in Table A-7, when compared to the data in Table A-1, indicate that the solid material was not fully dissolved in the large-scale mixing chamber test. A higher water velocity and greater size of water stream entering the mixing chamber is needed to improve dissolution.

Use of the mixing chamber concentrate for 1,000-square-foot fires reflects the inadequacy of this mixture (Table A-6, Tests 3, 4, and 7). Control and extinguishment times average 30 seconds and 60 seconds, respectively, compared to 18 seconds and 21 seconds, respectively, for QPL 3 percent AFFF.

3. Increased Agent - Propeller Mixing

Twenty-four 28-square-foot tests were performed using a solid agent/water ratio ranging from 6.6 g/L to 12 g/L. Concentrate samples were prepared using the propeller mixer. Data for these tests are recorded in Table A-3, Tests 3 through 8. The concentrates were allowed to stand between 1-6 days. Generally, there was no apparent increase in firefighting capability, although Test 4 (6.6 g/L) did meet MIL SPEC requirements for fire extinguishment time and time to 25 percent burnback.

4. 8 g/L - Propeller Mixer

Based on test results using 6 g/L and discussions with the manufacturer, ten 28-square-foot fire tests were performed, using 8 g/L solid-to-water ratio using the propeller mixer. Table 2 shows the average of the results; specific data are described in Table A-3. The average control, extinguishment and burnback time of the 10 tests is 25 seconds, 34 seconds and 311 seconds, respectively. The average values do not meet MIL SPEC requirements and are not equivalent with test results using 3M 3 percent QPL AFFF. Tests 17 and 18 in Table A-3 indicate the

results for 8 g/L tests using a new Lot of solid agent prepared by 3M Co. Test 8 did meet the fire extinguishment requirement of the MIL SPEC, but did not meet burnback requirements. There was not sufficient change or improvement in the results from these tests to warrant additional tests with the new Lot.

5. 8 g/L - Pipe Chamber

The pipe chamber method of mixing was used to dissolve solid AFFF directly into a solution at 8 g/L solid-to-water ratio. It appeared that the solid agent was adequately mixed in 3 minutes or less, although, in some cases, recirculation time up to 10 minutes was used. A further discussion of dissolving time in the pipe chamber is described in Section III.C.

Table 2 shows the average 8 g/L pipe chamber mixing results. Average control, extinguishment and burnback time are 23 seconds, 33 seconds and 331 seconds, respectively. This does not meet MIL SPEC requirements and is not equivalent with the QPL 3 percent results. The average 90 percent control, extinguishment and burnback times for QPL 3 percent AFFF are 17, 26 and 464 seconds, respectively. Of the 10 tests, Tests 19 and 21 meet MIL SPEC requirements for extinguishing time and burnback (control time is not a requirement in the MIL SPEC). Since Test 19 passed the MIL SPEC extinguishing and burnback time requirements, the MIL SPEC requirement for film and seal capability was run on this sample (a pilot flame passed over a small- scale fuel/foam sample resulted in sustained ignition). The material failed. No other samples were checked for film and seal capability.

Table A-5 shows the results of 50-square-foot fire tests. The average control and extinguishment time for three tests conducted with solid agent at 8 g/L are 32 seconds and 60 seconds, respectively. Burnback tests were not performed. The average control and extinguishment times for QPL 3 percent AFFF are 26 seconds and 40 seconds, respectively. The MIL SPEC requires extinguishing within 50 seconds (control time determination is not required). Solid agent mixed at 8 g/L in Test 4, and recirculated just prior to the test, meets the extinguishing requirements of the MIL SPEC. The 40-second summation time for this test was less than 320 seconds.

A single 1,000-square-foot test using 8 g/L solid-to-water ratio resulted in control and extinguishment times of 16 seconds and 44 seconds, respectively (Table A-6). The average of five 1,000-square-foot tests conducted with QPL 3 percent AFFF are 18 seconds and 31 seconds, respectively, for control and extinguishment time.

C. LARGE-SCALE MIXING ANALYSIS

A number of factors influence mixing and dissolving of the solid agent, including type of mixing equipment (e.g., propeller mixer, mixing chamber and pipe chamber), storage time (time between dissolving and use), preparation as a concentrate or solution, and solid agent/water ratio. Other factors which were not investigated in this evaluation include temperature and aging.

Tables 2 and 3 attempt to quantify any relationships in the mixing factors, since conflicting information was received from the manufacturer regarding mixing techniques, aging and storage. It should be recognized that the manufacturer's primary research, development and marketing efforts have focused on the "solid charge" concept; i.e., a foam is created and immediately used by passing a water stream through the solid agent, without recirculation. A portable fire extinguisher using a solid AFFF charge is commercially available. For this project, it was considered that the agent will be mixed and stored, for at least a few hours and likely much longer.

Table 1 summarizes data for the 8 g/L tests using the pipe chamber dissolving technique to dissolve agent directly into a solution. This technique and agent/water ratio resulted in the best average performance. The data summarized in Tables 2 and 3 indicate the following:

1. There is no apparent difference in the performance of solid AFFF when prepared either as a concentrate or solution;

2. The pipe chamber mixing technique constitutes no significant improvement in mixing (based on fire performance data) compared to the propeller mixer. The mixing chamber technique can probably be improved to dissolve the solid agent within the required time period (i.e., increase the diameter of the inlet and outlet connections and increase the flow rate through the chamber);

3. All test fires were extinguished using solid AFFF solution;

4. Storing the agent after dissolving into a concentrate or solution may adversely affect fire performance, but the data are not sufficient to identify the degree of the problem. The data in Table 2 indicate that, for the 28-square-foot fire tests, 8 g/L solutions with storage times of less than 5 minutes performed slightly better than solutions which had longer storage times. In the 50-square-foot fire tests, the 8 g/L solution,

after recirculation, performed much better than earlier tests (Table A-5, Test 4). On the other hand, in three of the four solid agent tests which passed the MIL SPEC extinguishing criteria (Tests 4, 8, 19, and 21), the agent had been allowed to sit or "settle" after dissolving for more than 5 minutes. Five minutes is about as fast as the agent can be prepared and transferred to the equipment for testing. Also, there are scenarios where a dissolved solid agent could sit in a crash rescue vehicle for extended time periods;

5. One sample passed the MIL SPEC 28-square-foot requirements using a 6.6 g/L solid/water ratio, although the foam was observed to be of poor quality (flames leaked through the foam blanket);

6. Although the 8 g/L solutions did outperform the 6 g/L solutions, solutions prepared at 12 g/L and tested on the 28-square-foot fire did not show any improvement over the 6 and 8 g/L tests (Table A-3, Tests 6 and 7);

7. The refractive index data in Table 3 indicate that minor changes at the upper end of the refractive index (1.3339-1.3341) should not be used to predict an increase or decrease in fire performance. The data in Table 3 also indicate that dissolving for charges up to 250 pounds can be accomplished in 3 minutes or less when converted directly to a solution;

8. The solid agent will not "self-mix," i.e., solid agent poured into a container of water will sink and not completely dissolve; and

9. A precipitate was observed in some of the propeller mix concentrate samples.

SECTION IV

OBSERVATIONS AND CONCLUSIONS

A. OBSERVATIONS

1. Fire Test Results

The solid agent, proportioned at 6 g/L or 8 g/L, cannot consistently perform as well as current QPL 3 percent foam supplied by 3M. Given a sufficient number of trials, the solid AFFF would probably pass the fire performance requirements of the current MIL SPEC, but not on a regular basis. On a larger scale (1,000-square-foot), the single 8 g/L test using the pipe chamber mixing method was equivalent to one of the QPL 3 percent tests, although it was not equivalent to the average of all QPL 3 percent tests (See Table A-6). In all tests, the solid AFFF did extinguish the fire.

In many of the small-scale tests, the foam prepared using the solid AFFF was noted as having a slow initial knock down and allowing a reflash across the surface of the fuel after 90 percent control had been achieved (i.e., the foam is "leaky"), as verified in Test 19 where the foam passed the extinguishing and burnback criteria but failed the film and seal test. A good quality AFFF which consistently meets the MIL SPEC requirements has quick knockdown and sealing capability.

While the data may indicate that the solid agent AFFF is comparable to QPL 3 percent AFFF, the poor foam quality, "leaky" characteristics and poor burnback performance make it undesirable as a substitute for the liquid concentrate.

2. Fluorine Content

Early formulations of AFFF utilized water-soluble perfluorocarbon type surfactants and other agents capable of forming vapor-securing foams and films on hydrocarbon fuel substrates (Reference 2). Subsequent formulations have used a combination of fluorinated and fluorine free surfactants (Reference 3). While it is not appropriate to draw a direct correlation between fire performance and fluorine content of an AFFF, it is interesting to note that the solid agent supplied by the manufacturer has approximately two-thirds the fluorine content, when proportioned at 6 g/L, of QPL 3 percent AFFF provided by the same manufacturer. The 3M Company has indicated in telephone conversations that composition changes made to improve the agent would involve increasing the fluorine content.

3. Mixing

Any future investigation of solid AFFF agent should evaluate the impact of storage time. This should include accelerated aging tests. Independent of fire performance, the pellet as manufactured can probably meet the 3-minute dissolving criteria established by the USAF/Navy. The optimum velocity of a water stream needed to dissolve large charges of agent within 3 minutes has not been sufficiently quantified, however, preliminary tests indicate that the necessary velocity can be achieved by equipment currently on board P-4/P-19 crash rescue vehicles. Further investigations should determine if concentrates can be prepared on a large scale (the pipe chamber mixing method used in these experiments converted solid AFFF agent directly to solution because the quantity of water needed to fill the pump, hose lines, etc. and the limited supply of solid agent precluded dissolving the solid agent into a concentrate).

B. CONCLUSIONS

1. AFFF produced from the solid agent at a 6 g/L or 8 g/L solid to water ratio:

   a. Is not equivalent to 3M QPL 3 percent AFFF in fire extinguishment and burnback characteristics; and

   b. Cannot consistently pass MIL-F-24385C requirements for extinguishment and burnback time.

2. Material changes to the solid agent are required to improve fire-extinguishing and burnback characteristics if a mixing ratio of 8 g/L or less is to be maintained.

3. A dissolving time of 3 minutes or less appears feasible.

4. Storage time between dissolving and use of a concentrate or solution prepared using solid AFFF will impact fire performance; additional testing is needed to quantify the degree of this problem. This will have an impact on the intended field use of the solid AFFF.

5. Reductions in weight of 73 percent and in storage space of 68 percent can be achieved by using solid AFFF at 8 g/L, as compared with 3 percent liquid concentrate.

SECTION V

RECOMMENDATIONS

Even at 8 g/L, solid AFFF provides substantial weight (73 percent) and space (68 percent) reductions over 3 percent liquid concentrate. Because of the combination of marginal fire performance and burnback characteristics (with respect to QPL liquid concentrate) and the sensitivity to storage, further hardware and specification work for the solid AFFF at 8 g/L is not recommended. However, the merits of reduced volume and weight, from a logistics standpoint, justifies further development work in this area. Two approaches are recommended: continued development of a solid agent and investigation of more concentrated liquid agents.

A. CONTINUED DEVELOPMENT OF SOLID AFFF

A determination must be made whether reduced space and weight savings resulting from increased solid/water ratios are acceptable. Table 4 shows space and weight comparisons between 3 percent concentrates and increased solid to water ratios. Twenty-eight square-foot and 1,000-square-foot fire tests would be performed, using the pipe chamber mixing method to determine whether increased agent/water ratios are effective. The fire testing would be deemed successful if fire performance is consistently equivalent to QPL 3 percent concentrate for extinguishment and burnback and the foam quality is not "leaky." The solution would be mixed and stored to settle for a predetermined length of time. If the pellets now being manufactured are to be used, firefighting capability should be sufficient to overcome any variations resulting from storing the solution which would be reasonably expected under actual field (wartime environment) use.

Space and weight of the mixing chamber should be factored in with the overall space and weight savings comparison of the solid agent vs. liquid concentrate.

If increased agent/water ratios greater than 6 or 8 g/L are not acceptable or the increased agent tests fail the fire performance criteria, then the next step requires reformulation of the agent. The manufacturer has indicated that this is feasible. To date, they have been unwilling to make commitments to reformulate the agent without government financial support. In addition to improved fire extinguishing and burnback characteristics, any reformulation should attempt to reduce any sensitivity to mixing or storage.

Another alternative would be to proceed directly to the design where a water stream passes directly through a solid

TABLE 4. SPACE AND WEIGHT SAVINGS OF NEW AGENTS COMPARED TO 3 PERCENT CONCENTRATE

	Percent Weight Reduction Over 3 Percent Concentrate	Precent Volume Reduction Over 3 Percent Concentrate
Solid at 6 g/L	80	76
Solid at 8 g/L	73	68
Solid at 10 g/L	67	60
Solid at 12 g/L	60	52
1% Liquid Concentrate	63*	67
3/4% Liquid Concentrate	73*	75

*Assumes specific gravity of 1.1.

"charge" to form AFFF solution, without recirculation. Potential problems to be solved include sizing of the charge for varied flow rates and space and weight-sensitive design for large flow streams. Given the problems identified in this phase, and a probable requirement to restructure the size of the pellet for large flow rate water streams, it is not recommended to proceed directly to a solid-charge type design at this time. Prototype solid agent cartridges are now commercially available for 1 1/2-inch diameter handlines, and should be tested.

An additional factor influencing the decision to proceed with solid agent is the end cost. Presently, because of increased manufacturing process steps in the production of the solid agent, the cost may be three to five times greater than liquid concentrates.

B. SUPERCONCENTRATED AFFF

During initial discussions with the AFESC/NAVAIR, the 3M Company also proposed the use of superconcentrated AFFF, i.e., foam which can be proportioned at rates lower than 3 or 6 percent. 3M and other manufacturers now have commercially available 1 percent AFFF concentrates. 3M and the ANSUL Co. are also working with 3/4 percent concentrate formulations; however no concentrates less than 1 percent are now commercially available. A superconcentrate, as shown in Table 4, provides potential weight and space savings over 3 percent concentrate which approach the weight and space savings of solid AFFF.

Advantages of a liquid superconcentrate are elimination of dissolving/mixing equipment and probable lower end cost per unit volume. Available large-scale test results on 1 percent agent indicate that the fire performance characteristics are comparable to QPL 3 percent and 6 percent foam approved under the previous version of the MIL SPEC (Reference 4). The ability of 1 percent agent to meet current MIL SPEC requirements would have to be verified.

The primary drawback to the superconcentrate concept is the design of a reliable proportioning system for very low proportioning rates. Also there are no freeze-protected superconcentrates currently commercially available. If a 1 percent proportioning system were to be developed, the tolerances would have to be very stringent to prevent a proportion of agent to water either too high or too low. Work conducted at NRL with the balanced pressure proportioning system indicates that proportioning at 1 percent may be feasible. Modification to crash rescue vehicles, such as the new P-19, may only involve changes to proportioning system orifice plates. Other possibilities include premixing the agent in the crash rescue vehicle water storage tank or developing an injection system

which would inject concentrate directly into the water tank with some type of agitation to provide adequate mixing.

A variation of the superconcentrate concept is to start with a solid or liquid to which water is added to create or "reconstitute" a 3 or 6 percent AFFF concentrate ready for proportioning. This method is used in the manufacture of AFFF concentrates.

C. SPECIFIC RECOMMENDATIONS

Based on the fire performance evaluation and preliminary mixing evaluation of solid AFFF, the following actions are recommended:

1. Continue the efforts to reduce space and weight requirements of firefighting agents for crash rescue vehicles;

2. Perform increased agent (e.g., 10 g/L, 12 g/L) tests using the on-hand solid agent and the pipe chamber mixing method. This would give a better indication whether the currently manufactured agent can consistently perform in a manner equivalent to QPL AFFF. If performance is sufficiently improved, quantify the storage issue by performing additional storage time and aging tests with concentrates and solutions;

3. Perform an initial fire performance evaluation of super-concentrated AFFF samples and formulations which can be reconstituted as provided by manufacturers. Initial tests would be similar to those conducted for solid AFFF, e.g., 28-square-foot, 50-square-foot, and 1,000-square-foot tests compared against QPL 3 percent AFFF;

4. Review current equipment and capability to produce reliable proportioning systems for superconcentrates and evaluate alternative proportioning schemes for retrofitting crash rescue vehicles for superconcentrates; and

5. Based on the factors discussed in this report, the outcome of the increased agent tests, and the initial evaluation of superconcentrates, review the effectiveness of continued R & D on solid AFFF for application to crash rescue vehicles. Test in-line solid cartridges (60 gpm and 95 gpm) to determine fire performance and burnback in a "direct to solution" set-up.

REFERENCES

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APPENDIX A

TEST DATA

TABLE A-1. REFRACTIVE INDEXES OF AFFF SAMPLES

	Refractive Index			
Total Solution	3M 203CE	Solid AFFF Trial 1	Solid AFFF Trial 2	Solid AFFF Trial 3
50 ml (3% concentrate)	1.3773	1.3544	1.3529	1.3529
100 ml	1.3553	1.3433	1.3437	1.3436
150 ml	1.3477	1.3397	1.3401	1.3401
200 ml	1.3442	1.3374	1.3381	1.3383
800 ml	1.3354	1.3339	1.3340	1.3340
1250 ml (8 g/L solid)	1.3345	1.3333	1.3334	1.3335
1666 ml (6 g/L solid)	1.3341	1.3332	1.3331	1.3332
2500 ml	1.3335	1.3330	1.3329	1.3329

3M 203 CE- Start with 50 ml of 3 percent concentrate.

Solid AFFF - Start with 50 ml of water and 9.95 g of solid agent.

Distilled water used (refractive index 1.3327); constant temperature of 25°C ± 2°C.

Lab stirring rod used to mix solid agent.

TABLE A-2. FLUORINE CONTENT OF AFFF SAMPLES

Sample	Concentrate/ Solution	Mixing Method	Percent Fluorine By Weight
3M 203CE	Concentrate	N/A	2.05
Solid	Concentrate 1.66 lbs/gal	Bench Scale	1.04
Solid	Concentrate 2 lbs/gal	Bench Scale	1.02
Solid	Concentrate 2 lbs/gal	Propeller Mixer	1.13
Solid	Concentrate 3.32 lbs/gal	Bench Scale	2.01
Solid	Concentrate 3.32 lbs/gal	Propeller Mixer	2.05
3M 203CE	3% Solution	N/A	0.06
Solid	3% Solution (6 g/L)	Bench Scale	0.04
Solid	6% Solution (12 g/L)	Propeller Mixer	0.07

TABLE A-3. SOLID AFFF 28-SQUARE-FOOT FIRE TESTS

Test No.	Date Performed	Solid/Water Solution Ratio (g/L) Prepared as Concentrate or Solution	Time From Mix to Use	90 Percent Control Time (Sec.)	Extinguishment Time (Sec.)	Time to 25 Percent Burnback (Sec.)
1	4/23/84	6 - C[1]	P[2] - 17 days	25	35	--
2	4/23/84	6 - C	P - 17 days	20	36	--
3	5/31/84	6.6 - C	P - 6 days	25	40	324
4	5/31/84	6.6 - C	P - 6 days	19	30	360
5	5/31/84	7.2 - C	P - 6 days	20	36	330
6	5/31/84	7.2 - C	P - 6 days	20	35	348
7	5/31/84	12 - C	P - 1 day	32	43	338
8	5/31/84	12 - C	P - 1 day	30	33	304
9	7/18/84	6 - C	P - 5 min. (remixed)[3]	29	38	337
10	7/18/84	6 - C	P - 20 min. (remixed)	28	42	288
11	7/18/84	8 - C	P - 5 min. (remixed)	27	35	306
12	7/18/84	8 - C	P - 20 min. (remixed)	28	31	299
13	7/18/84	8 - S[4]	P - 5 min.	23	33	320
14	7/18/84	8 - S	P - 20 min.	27	39	309
15	7/20/84	8 - S	PC[5] - 45 min.	26	32	309
16	7/20/84	8 - S	PC - 1 hour	26	39	297
17	8/01/84	8 - C	P (new lot) - 1 hr.	25	30	320
18	8/01/84	8 - C	P (new lot) - 75 min.	26	40	313
19	8/28/84	8 - S	PC - 5 min.	20	25	378
20	8/28/84	8 - S	PC - 20 min.	27	34	317
21	9/14/84	8 - S	PC - 17 days	18	30	376
22	9/14/84	8 - S	PC - 17 days	20	36	--
23	9/14/84	8 - S	PC - 5 min.	28	37	320
24	9/14/84	8 - S	PC - 20 min.	22	32	323
25	9/14/84	8 - C	P - 5 min. (remixed)	27	33	324
26	9/14/84	8 - C	P - 20 min. (remixed)	27	34	291
27	9/14/84	8 - S	P - 5 min.	20	32	322
28	9/14/84	8 - S	P - 20 min.	20	37	310 (est.)
	Average	8 g/L (8 tests)	PC	23	33	331
	Average	8 g/L (10 tests)	P	25	34	311
	Average	6 g/L (4 tests)	P	26	38	313

Notes:
C - prepared as a concentrate
P - propeller mixer
Remixed - concentrate prepared at earlier date and remixed for a minimum of 1 hr. prior to test; in some cases, additional solid agent was added to increase solid/water ratio.
S - prepared as a foam solution
PC - pipe chamber

TABLE A-2. FLUORINE CONTENT OF AFFF SAMPLES

Sample	Concentrate/ Solution	Mixing Method	Percent Fluorine By Weight
3M 203CF	Concentrate	N/A	2.05
Solid	Concentrate 1.66 lbs/gal	Bench Scale	1.04
Solid	Concentrate 2 lbs/gal	Bench Scale	1.02
Solid	Concentrate 2 lbs/gal	Propeller Mixer	1.13
Solid	Concentrate 3.32 lbs/gal	Bench Scale	2.01
Solid	Concentrate 3.32 lbs/gal	Propeller Mixer	2.05
3M 203CE	3% Solution	N/A	0.06
Solid	3% Solution (6 g/L)	Bench Scale	0.04
Solid	6% Solution (12 g/L)	Propeller Mixer	0.07

TABLE A-3. SOLID AFFF 28-SQUARE-FOOT FIRE TESTS

Test No.	Date Performed	Solid/Water Solution Ratio (g/L) -Prepared as Concentrate or Solution	Time From Mix to Use	90 Percent Control Time (Sec.)	Ext'g. Time (Sec.)	Time to 25 Percent Burnback (Sec.)
1	4/23/84	6 - C[1]	P[2] - 17 days	25	35	--
2	4/23/84	6 - C	P - 17 days	20	36	--
3	5/31/84	6.6 - C	P - 6 days	25	40	324
4	5/31/84	6.6 - C	P - 6 days	19	30	360
5	5/31/84	7.2 - C	P - 6 days	20	36	330
6	5/31/84	7.2 - C	P - 6 days	20	35	348
7	5/31/84	12 - C	P - 1 day	32	43	338
8	5/31/84	12 - C	P - 1 day	30	33	304
9	7/18/84	6 - C	P - 5 min. (remixed)[3]	29	38	337
10	7/18/84	6 - C	P - 20 min. (remixed)	28	42	288
11	7/18/84	8 - C	P - 5 min. (remixed)	27	35	306
12	7/18/84	8 - C	P - 20 min. (remixed)	28	31	299
13	7/18/84	8 - S[4]	P - 5 min.	23	33	320
14	7/18/84	8 - S	P - 20 min.	27	39	309
15	7/20/84	8 - S	PC[5] - 45 min.	26	32	309
16	7/20/84	8 - S	PC - 1 hour	26	39	297
17	8/01/84	8 - C	P (new lot) - 1 hr.	25	30	320
18	8/01/84	8 - C	P (new lot) - 75 min.	26	40	313
19	8/28/84	8 - S	PC - 5 min.	20	25	378
20	8/28/84	8 - S	PC - 20 min.	27	34	317
21	9/14/84	8 - S	PC - 17 days	18	30	376
22	9/14/84	8 - S	PC - 17 days	20	36	--
23	9/14/84	8 - S	PC - 5 min.	28	37	320
24	9/14/84	8 - S	PC - 20 min.	22	32	323
25	9/14/84	8 - C	P - 5 min. (remixed)	27	33	324
26	9/14/84	8 - C	P - 20 min. (remixed)	27	34	291
27	9/14/84	8 - S	P - 5 min.	20	32	322
28	9/14/84	8 - S	P - 20 min.	20	37	310 (est.)
	Average	8 g/L (8 tests)	PC	23	33	331
	Average	8 g/L (10 tests)	P	25	34	311
	Average	6 g/L (4 tests)	P	26	38	313

Notes:
C - prepared as a concentrate
P - propeller mixer
Remixed - concentrate prepared at earlier date and remixed for a minimum of 1 hr. prior to test; in some cases, additional solid agent was added to increase solid/water ratio.
S - prepared as a foam solution
PC - pipe chamber

TABLE A-4. 3M FC 203 3 PERCENT AFFF 28-SQUARE-FOOT FIRE TESTS

Test No.	Date	Agent	90 Percent Control Time (sec.)	Exting. Time (sec.)	Time to 25 Percent Burnback (sec.)
1	3/20/84	Lot 501	--	22	383
2	3/20/84	Lot 1	--	23	> 420
3	4/23/84	Lot 501	15	21	600
4	8/28/84	203-CE	18	31	522
5	8/28/84	203-CE Jim Speake operator	28	49	--
Previous Tests					
	10/22/81	QPL Aged Premix	17	26	432
	10/23/81	QPL Aged Premix	18	28	468
	9/30/81	QPL PKP Compat.	17	22	468
	9/30/81	QPL Fire Ext.	17	27	430
	9/29/81	QPL Fire Ext.	18	30	450
	Average 1984 Tests (5 tests)		20	29	481
	Average All Tests (10 tests)		19	28	464
	*Average All Tests except Test #5		17	26	464

*Inclusion of Test 5 increases the standard deviation in the extinguishment results from 3.71 to 8.19.

TABLE A-5. 3M FC 203 3 PERCENT AND SOLID AFFF 50-SQUARE-FOOT FIRE TESTS

Test No.	Date	Agent	90 Percent Control Time (sec.)	Exting. Time (sec.)	40 Sec. Sum. (Per- cent)	Time to 25 Percent Burnback (sec.)
1	8/24/84	FC 203-CE	25	36	341	630
2	8/28/84	Solid, 8 g/L pipe chamber mix, est. 4 hrs. mix to use	35	69	250	--
3	8/28/84	Solid, 8 g/L pipe chamber mix, ext. 4 hrs. mix to use	30	65	260	--
4	8/28/84	Solid, 8 g/L pipe	30	45	290	--
Previous 203 3 Percent Concentrate Tests						
	2/13/84	FC 203-CE (wind a factor) Chemlite plant salt-water	30	49	320	515
	2/13/84	Test #1 Saltwater	24	36.5	343	435
	1/08/82	FC 203-C #38, Saltwater	33	33	364	480
	1/08/82	#39, Saltwater	20	46	357	484
	Average 8 g/L (3 tests)		32	60	266	--
	Average FC 203 3 Percent (5 tests)		26	40	345	509

TABLE A-6. 3M 203 3 PERCENT AFFF AND SOLID AFFF 1000-SQUARE-FOOT FIRE TESTS

Test No.	Date	Agent	Mixing Method - Time From Mix To Use	90 Percent Control Time (sec.)	Exting. Time (sec.)
1	5/15/84	203-CE	--	20	30
2	5/15/84	203-CE	--	16	21
3	5/15/84	Solid 6 g/L	Mixing Chamber - 5 days	29	52
4	5/15/84	Solid 6 g/L	Mixing Chamber - 5 days	--	69
5	5/15/84	Solid 6 g/L	Propeller Mixer - 40 days	24	48
6	5/17/84	203-CE	--	15	26
7	5/17/84	Solid 6 g/L	Mixing Chamber - 7 days	30	78
8	5/17/84	Solid 6 g/L	Propeller Mixer - 42 days	20	69
9	8/28/84	203-CE	--	20	45
10	8/28/84	Solid 8 g/L	Pipe Chamber - est. 90 min.	16	44
		Average	203-CE (4 tests)	18	31

TABLE A-7. REFRACTIVE INDEXES OF SOLID AFFF CONCENTRATE DISSOLVED IN MIXING CHAMBER

Recirculation Time (Min)	Refractive Index Sample 1	Refractive Index Sample 2
0.5	1.3346	1.3341
1.0	1.3346	1.3347
1.5	1.3353	1.3353
2.0	1.3362	1.3361
2.5	1.3366	1.3365
3.0	1.3384	1.3383
10	1.3471	1.3471
FULL STRENGTH SAMPLES		
CONTAINER 1	1.3457	1.3455
CONTAINER 2	1.3458	1.3458
CONTAINER 3	1.3468	1.3469
CONTAINER 4	1.3452	1.3455
CONTAINER 5	1.3460	1.3466
CONTAINER 6	1.3460	1.3462
CONTAINER 7	1.3462	-
CONTAINER 8	1.3453	-
CONTAINER 9	1.3458	-

Average Full Strength - 1.3459; "Concentrate," prepared using 200 g/L

END
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